Impact of the screen configurations on the estimated Terra MODIS SD degradation

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ABSTRACT

The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on-board the Aqua and Terra spacecraft have collected valuable Earth data for the last 19 and 21 years, respectively. MODIS is equipped with various on-orbit calibrators, including a solar diffuser (SD) and solar diffuser stability monitor (SDSM), that are used to monitor changes in the instrument's gain over time. Nominally, SD calibrations alternate between two configurations: screen open and screen closed. Terra MODIS, however, experienced an anomaly in 2003, which has left the SD door and screen in a permanent open-closed configuration. This resulted in accelerated degradation of the SD on Terra MODIS due to the direct solar radiation exposure every orbit. It also led to an unexpected divergence between the calibration coefficients, m_1, or the inverse of the gain, generated using SD data and those generated using lunar observations at the time of the 2003 anomaly. This paper examines the effect of the screen configuration on the Terra SD degradation by analyzing Terra SDSM data and comparing to Aqua. We generate "pseudo-open" Terra SDSM data by modeling the ratio of Aqua screen open and screen closed SDSM data and calculate the Terra SD degradation using this new screen open data. We then examine the effects on our m_1 values calculated using this new pseudo-open SD degradation for Terra. Implementing this new degradation results in a smaller discrepancy between the lunar and SD m_1 values after the door anomaly, indicating that there may be a systematic error in the SD degradation calculated with screen closed data.

Keywords: MODIS, Terra, Solar Diffuser, Solar Diffuser Stability Monitor

1. INTRODUCTION

The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on-board the Terra and Aqua spacecraft have collected a wealth of Earth data throughout the past two decades.[1,2] MODIS is equipped with 36 spectral bands, including reflective solar bands (RSBs) and thermal emissive bands (TEBs) that are able to collect data within wavelength ranges of 0.4 to 2.1 μm and 3.7 to 14.1 μm, respectively.[1] By observing at this range of wavelengths as well as at different nadir spatial resolutions, MODIS is able to glean valuable information about the Earth's atmosphere, land, and oceans.

As MODIS is continuously exposed to solar radiation throughout its orbit, the optics within the instrument naturally begin to degrade. In order to account for this degradation and accurately calibrate the Earth view data products, MODIS uses a set of on-board calibrators (OBCs) to track changes in the instrument gain, as well as changes to optics, detectors, or electronics on orbit. These OBCs are used to monitor the instrument's health and include a solar diffuser (SD), solar diffuser stability monitor (SDSM), blackbody (BB), and spectroradiometric calibration assembly (SRCA).[1] The primary OBCs implemented in this analysis are the SD and SDSM and will be described in further detail below.

The SD and SDSM are utilized about every three weeks for calibrations near the North Pole for Terra and South Pole for Aqua to help monitor gain changes within the RSBs of MODIS. The SD is a Spectralon plate with near Lambertian reflectivity that was characterized pre-launch;[3,4] however, due to radiation exposure throughout the past two decades, the SDs on Aqua and Terra have both exhibited degradation. To track the degradation of the SD's reflectance over time at multiple wavelengths, we monitor the ratio of the SD and Sun response observed

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by the nine detectors in the SDSM. During SD/SDSM calibrations, the SD door (SDD) is opened in order to allow solar radiation to enter the calibration assembly, and the SD screen (SDS) is moved in tandem with the SDD to either an open or closed position. The SDS decreases radiation transmission in the SD viewing direction by about 92.2%; this is useful for calibrating high gain MODIS Bands 8-16, which are nominally saturated when the screen is not in place.[4] A separate attenuation screen in the SDSM Sun view direction is fixed in place to allow only 1.44% of incoming solar radiation to enter the SDSM assembly, which creates similar signal levels between the Sun and SD views on the SDSM detectors.[4] Throughout a typical SDSM calibration performed in alternating mode, a mirror within the SDSM changes position every scan (1.447 seconds), collecting data from the SD view, Sun view, and a dark view within the SDSM chamber on sequential scans. A schematic summarizing this set up can be seen in Figure 1. By collecting data from these different viewing directions, we are able to track changes in the SD reflectance by taking the ratio of the digital counts observed when viewing the SD view compared to those when viewing the Sun view. We also gain meaningful information from the SDSM about any instrument background or stray light that is present.

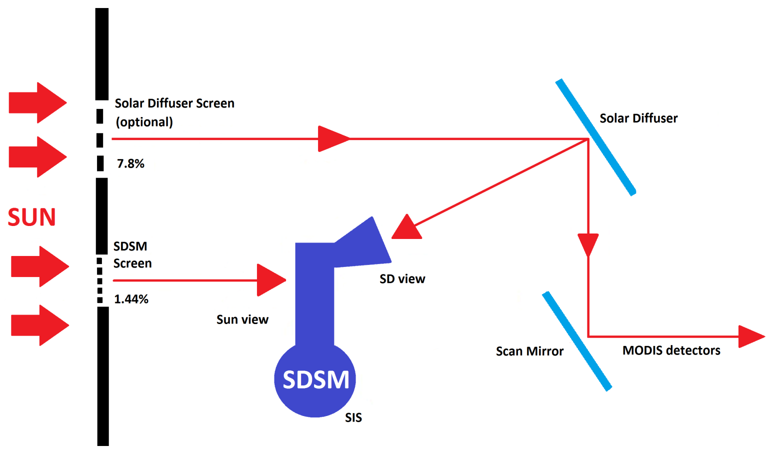

Figure 1. Schematic of the MODIS SDSM and SD. Arrows indicate directional path of photons. The SDS that is moved for calibrations is denoted in the upper left-hand portion of the figure, while the solar attenuation screen is represented by the SDSM screen in the lower left-hand portion of the figure.

In addition to monitoring the health of the instrument, these SD/SDSM calibrations are used to calculate the calibration coefficient for each MODIS RSB detector, m_1, that the MODIS Characterization and Support Team (MCST) computes in order to convert raw MODIS signals to top-of-atmosphere (TOA) reflectance. This calibration coefficient depends directly on the degradation of the SD, namely by Equation 1,

$$m_1 = \frac{\rho_{SD}\ cos(\theta_{SD})\ \Delta_{SD}\ \Gamma_{SDS}}{dn^*_{SD} d^2_{ES,SD}}, \tag{1}$$

where ρ_{SD} is the SD bidirectional reflectance factor, Δ_{SD} is the SD degradation, $d_{ES,SD}$ is the Earth-Sun distance in AU during the SD calibration, dn^*_{SD} is the digital number of the SD response after background and temperature correction, θ_{SD} is the solar zenith angle, and Γ_{SDS} is the SDS vignetting function. During screen open calibrations, $\Gamma_{SDS} = 1$. The calibration coefficient m_1 is directly utilized in calculating the TOA reflectance that is ultimately delivered to science teams, which can be expressed by Equation 2,

$$\rho_{EV} cos(\theta_{EV}) = \frac{m_1 \cdot dn^*_{EV} \cdot d^2_{ES}}{RVS}, \tag{2}$$

where θ_{EV} is the solar zenith angle, m_1 is the calibration coefficient, dn^*_{EV} is the corrected Earth view digital signal, d_{ES} is the Earth-Sun distance in AU at the time of the measurement, and RVS is the response versus scan. From Equations 1 and 2, we can see that SD/SDSM calibrations are critical in maintaining the quality of

the MODIS science data products. It is therefore important for us to closely monitor any changes we may be seeing within the SDSM and SD as the Aqua and Terra missions progress.

In addition to SD/SDSM calibrations, Terra and Aqua MODIS utilize lunar data in order to characterize gain changes occurring within MODIS's optics. These lunar calibrations are conducted on a near monthly basis, celestial and instrumental geometry permitting.[5] The Moon acts as a good radiometric reference due to its stable reflectance and irradiance;[6–8] therefore, we are able to utilize lunar observations to monitor response changes within the visible and near-infrared bands of MODIS. Through lunar observations, we are able to obtain the m_1 calibration coefficient through Equation 3,

$$m_1^{moon} = \frac{f_{vg}}{\langle dn^*_{moon} \rangle}, \tag{3}$$

where dn^*_{Moon} is the corrected lunar digital signal, and f_{vg} is a model describing lunar irradiance as a function of viewing geometry.[9,10] By using multiple calibration sources like the Moon and SD, we are able to also track any changes that may be occurring within the reflectance of the scan mirror on MODIS.

Lunar calibrations are conducted through the space view (SV) port on-board MODIS at an angle of incidence (AOI) of 11.2° on MODIS's scan mirror, while SD measurements are taken at an AOI of 50.2°. The scan mirrors on-board Aqua and Terra MODIS have each demonstrated a reflectance dependence as a function of AOI, so these lunar and SD observations are key in characterizing any long term changes in the mirrors' reflectances on orbit. In MODIS Collection 6 and 6.1 (C6/C6.1) calibration, the on-orbit RVS change is calculated for most bands using the SD and lunar trends and a linear interpolation to obtain the RVS at all AOI. This linear RVS algorithm is applied to Aqua bands 10-19 and Terra bands 11-19. For Aqua bands 1-4 and 8-9 and Terra bands 1-4 and 8-10, the linear RVS is not adequate to track the on-orbit RVS changes, and data from desert targets are also used to aid in the calibration.

2. MOTIVATION

Approximately 3.5 years into its mission, Terra MODIS experienced an anomaly during one of its SD calibrations. Nominally after completing the SDS open calibrations, the SDD is commanded back into a closed position in order to protect the SD from excessive radiation exposure between calibrations. In mid-2003 during a SDS open calibration, the SDS remained in a closed configuration despite having been commanded to move to an open position. Due to the fact that the SDD and SDS operate using the same motor, this affected the entire SD and SDS system. This anomaly has resulted in a permanent SDD open and SDS closed configuration since 2003, resulting in accelerated degradation of the SD on-board Terra due to increased solar exposure. This anomaly has also forced us to conduct strictly SDS closed calibrations for Terra.

The SD degradation used in determining SD m_1 values in the C6/C6.1 algorithm is calculated from the full mission SDSM data. In this calculation, the SDS open calibration data are used for the time period from mission start to the 2003 anomaly since the SDS open calibrations have a higher signal level, higher signal-to-noise ratio, and are considered to be more accurate. After the 2003 anomaly, only SDS closed calibrations are available and must be used exclusively. Unlike Terra MODIS, the Aqua MODIS SDD and SDS continue to function normally, and we have both open and closed SDSM data throughout the entire Aqua mission. We recently[11] showed that there is a systematic difference between the Aqua SD degradation calculated with the open data compared to the closed data, and this difference changes in time over the Aqua mission with a magnitude of up to 2%. If a similar divergence exists for Terra MODIS, there may be a systematic error introduced into our Terra SD calibration after switching to using SDS closed data after the 2003 anomaly.

In addition, we notice unexpected behavior around the time of the SDD anomaly when comparing lunar and SD m_1 trends and the RVS derived from them. After the 2003 SDD anomaly, a divergence between the lunar and SD m_1 values began to appear for multiple RSBs. Examples of this can be seen in Figure 2 for bands 13 and 16, with the door anomaly event represented by the border between the gray and pink regions. Since the lunar and SD observations are made at different AOI, a difference in their trends is not necessarily concerning. However, it can be clearly seen in the two examples in Figure 2 that the SD and lunar trends change at nearly the same rate over the mission except for a period of roughly 1000 days following the SDD anomaly, where the

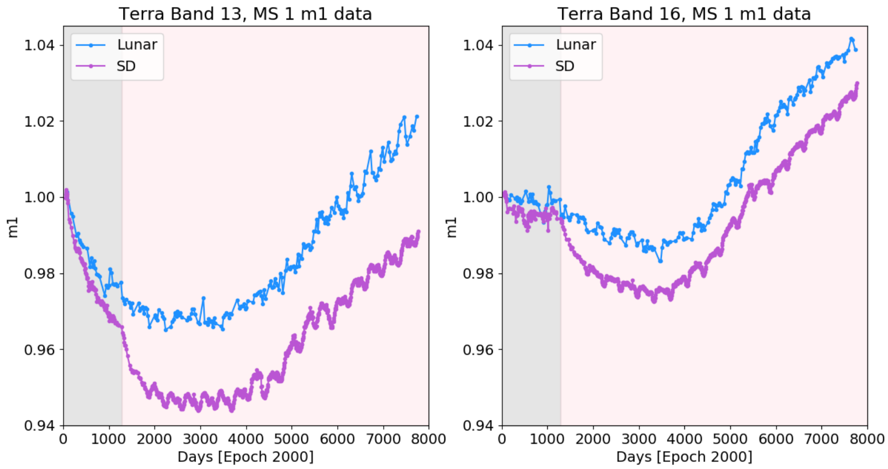

Figure 2. Terra Band 13 and Band 16 mirror side 1 m_1 data. Blue points represent lunar m_1 coefficients, purple points represent SD m_1 coefficients. Each point is the coefficient calculated from the monthly lunar calibrations and triweekly SDD closed calibrations. The gray region highlights dates prior to the Terra SDD failure on Day 1279, and the pink region highlights dates after the door anomaly.

SD trends show a sharp drop of 1% - 2% that is not present in the lunar trends. While the SDD anomaly clearly has a significant impact on the rate of SD degradation, it is not expected to have any impact on the degradation of the MODIS detector gains ($1/m_1$), so the divergence of the SD trend from the lunar trend right after the SDD anomaly may indicate a problem with the SD degradation accuracy.

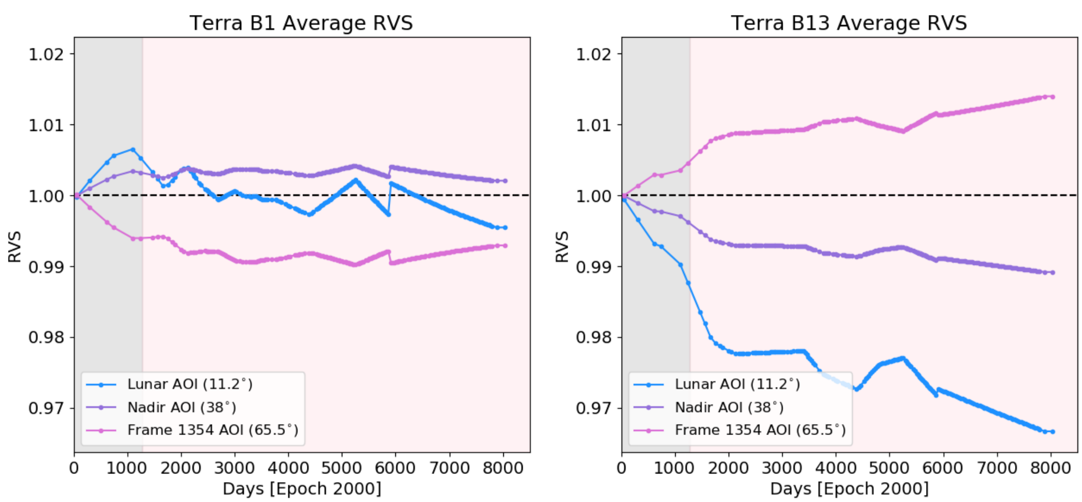

Figure 3. Example of Terra RVS for Bands 1 and 13, normalized to mission start. Average RVS at different AOI, which are indicated in each subplot's legend, are plotted for Bands 1 and 13. The gray region highlights dates prior to the door anomaly, while the pink region represents all dates after the SDD anomaly. Note that all RVS values are normalized to SD AOI, which is why the SD AOI curve is not included.

This effect can also be demonstrated by looking at the RVS trends. We also see a sharp change in the RVS that coincides with the SDD anomaly for bands that implement OBC data in their calculations, an example of which can be seen in Figure 3. Band 13 demonstrates a significant change in RVS following the door anomaly. This distinct change, however, is not present in the RVS data for Band 1, which employs only Earth view data from desert sites when deriving the RVS. Bands 1 and 13 have nearly identical center wavelengths, 645 nm and

667 nm, respectively, and should in principal demonstrate very similar behavior in their RVS trends. Any change in RVS over time would be a direct result of the scan mirror's reflectance changing due to prolonged radiation exposure. Since RVS strictly depends on the reflectance of the scan mirror and the incoming radiation, we would not anticipate this door anomaly to affect the trends we observe across all AOI.

Given these two observations - the known disagreement in the Aqua SD degradation calculated with SDS open versus SDS closed data and the unexpected RVS change observed at the time when Terra MODIS switches to using SDS closed data in SDSM calibration - we suspect that the inaccuracy of the SDS closed data in the SDSM calibration is causing an error in the Terra SD m_1 calibration and ultimately the RVS calibration for the bands using the linear RVS approach (Terra bands 11-19). In this paper, we further investigate this disagreement in the SDSM open versus closed data and use a simple method to attempt to mitigate its impact on the Terra calibration. We create a "pseudo-open" SD degradation dataset for Terra MODIS by utilizing Aqua MODIS SD data and assuming that Terra MODIS sees the same divergence of its open and closed SDSM data as Aqua. We implement this new "pseudo-open" data in our Terra SD m_1 and RVS calculations and see a reduced divergence in the m_1 and RVS trends following the SDD anomaly. The details of our approach and results are found in the following sections.

3. METHODOLOGY

MODIS SD calibrations are conducted on a triweekly basis for both Aqua and Terra, allowing us to monitor on-orbit changes at a relatively high frequency. The SDD on-board Aqua MODIS has functioned nominally throughout the duration of the mission, allowing us to conduct SDS open calibrations every six weeks and SDS closed calibrations every three weeks. Due to the door anomaly, Terra MODIS is only able to conduct SDS closed calibrations, which occur on a triweekly basis. We know that there is an inherent difference between screen closed and screen opened data from previous studies,[11] which is potentially responsible for the divergence we observe between the Terra lunar and SD m_1 coefficients after May 2003. We therefore want to examine the SDS open data collected by Aqua MODIS throughout the duration of its mission to help characterize this difference since Terra MODIS has extremely limited SDS open data from early mission.

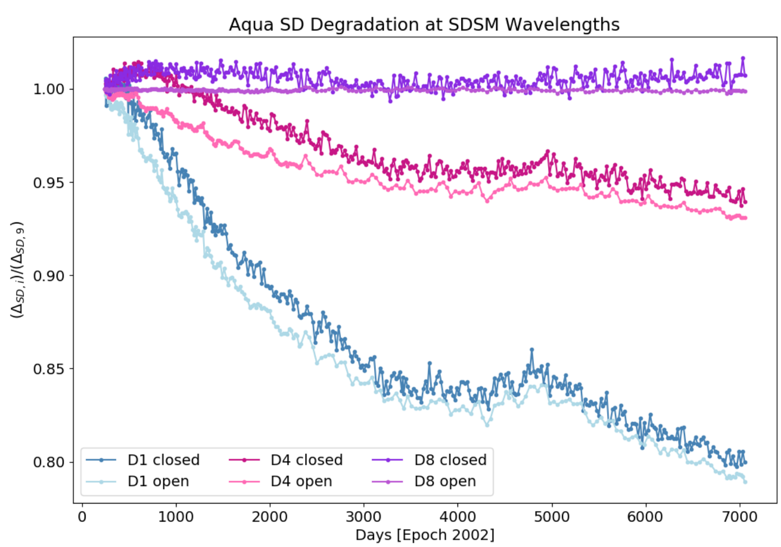

Figure 4. Aqua MODIS SD degradation at SDSM detector wavelengths 1, 4, and 8. Darker curves represent degradation values calculated using SDS closed data, while the lighter curves show degradation values calculated using SDS open data. Each point represents degradation value derived from one SD calibration. All degradation values are normalized to SDSM D_9.

We examine Aqua MODIS SDSM data collected in both open and closed SDS configurations and proceed to calculate the SD degradation at each of the nine SDSM detector wavelengths using Equation 4,

$$\Delta_{i,SD} = \frac{dn^*_{i,SD}}{dn^*_{i,Sun}}, \tag{4}$$

where dn^* is the geometrically and background corrected digital count data for each respective source and $i \in [1, 9]$ for each of the SDSM detectors. We normalize all detectors to D_9 in order to account for oscillations seen throughout the mission caused by a misalignment of the SDSM screen.[4,12] We calculate the normalized SD degradation, Δ_i/Δ_9, for each calibration, examples of which can be found in Figure 4, and find the instances during which both an open and closed calibration were performed within the same day. Once these corresponding calibrations are located, we proceed to take the ratio of the degradation calculated in each configuration; namely, $\frac{(\Delta_i/\Delta_9)_{open}}{(\Delta_i/\Delta_9)_{closed}}$.

This ratio is calculated for all Aqua SDSM data collected since mission start, resulting in an open-closed ratio profile for detectors 1-8. Detector 9 is excluded since this ratio is merely unity due to our normalization process. We proceed to analytically model these eight profiles using a piecewise superposition of a sixth order polynomial and linear function. The resultant profiles and fits can be seen in Figure 5.

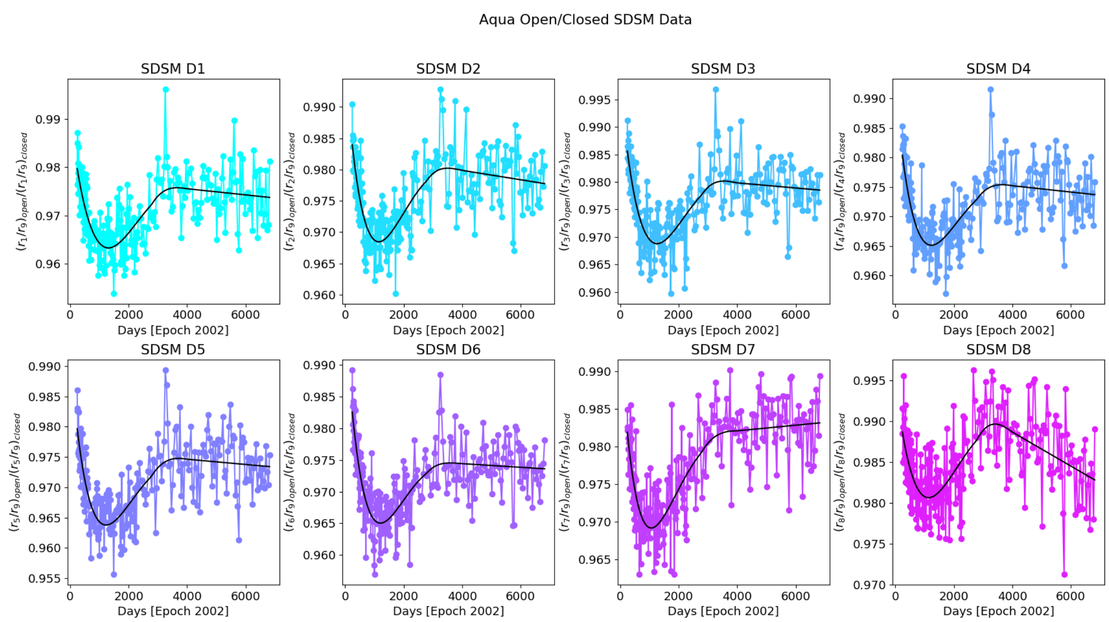

Figure 5. Open/closed ratio plots for Aqua SDSM detectors 1-8. The black curve represents the polynomial fit calculated for each detector. Each point represents the ratio between the SD degradation calculated using screen open and screen closed data for a single date. Note that open and closed calibrations were conducted at a higher frequency during early mission.

It is apparent from the data in Figure 4 and Figure 5 that that there is indeed an inherent difference between the SD data collected in open versus closed screen configurations for Aqua MODIS. The ratio of the two data sets evolves with time, with changes up to almost 2% at certain points in the mission. Assuming the SDS open trends are more accurate, using the SDS closed data for any part of the mission, as is done for Terra MODIS, would lead to inaccuracies in the SD degradation.

To investigate the potential impact on Terra, we assume that the Terra SD degradation open/closed ratio follows the same trend in time as exhibited by the SDSM detectors in Aqua, and we calculate a “pseudo-open” degradation using the models from Figure 5. This is naturally quite a large assumption to make, but early mission trends where both open and closed SDS data were available for Terra exhibit similar ratio trends to

those we observe for Aqua. We begin by shifting the Terra data relative to the Aqua mission start date using Equation 5,

$$t_{shift} = t_{Terra} + |t_{Aqua,start} - t_{Terra,start}|, \tag{5}$$

which relies on the assumption that Terra and Aqua exhibit the same open/close ratio trends over time. Once the Terra times are shifted as indicated in Equation 5, we multiply all measured Terra SD degradation data at SDSM wavelengths collected after the door anomaly in 2003 by the Aqua open-close model as shown in Equation 6,

$$\Delta^{Terra}_{SDSO,i} = \Delta^{Terra}_{SDSC,i} f(t,i), \tag{6}$$

where $f(t,i)$ is the polynomial fit computed using the Aqua $\Delta_{SDSO,i}$ and $\Delta_{SDSC,i}$ data for detectors $i \in [1,8]$. The resultant SD degradation, $\Delta^{Terra}_{SDSO,i}$, at SDSM wavelengths using this approach can be seen in Figure 6. Figure 6 shows that across all SDSM wavelengths, the psuedo-open data result in a slower rate of degradation than we are observing using the screen closed data. The difference in the degradation values found using SDS closed versus pseudo-open data is on the order of 1% for some SDSM detectors. This is important to note since the m_1 coefficients and ultimately TOA reflectance values depend directly on the SD degradation.

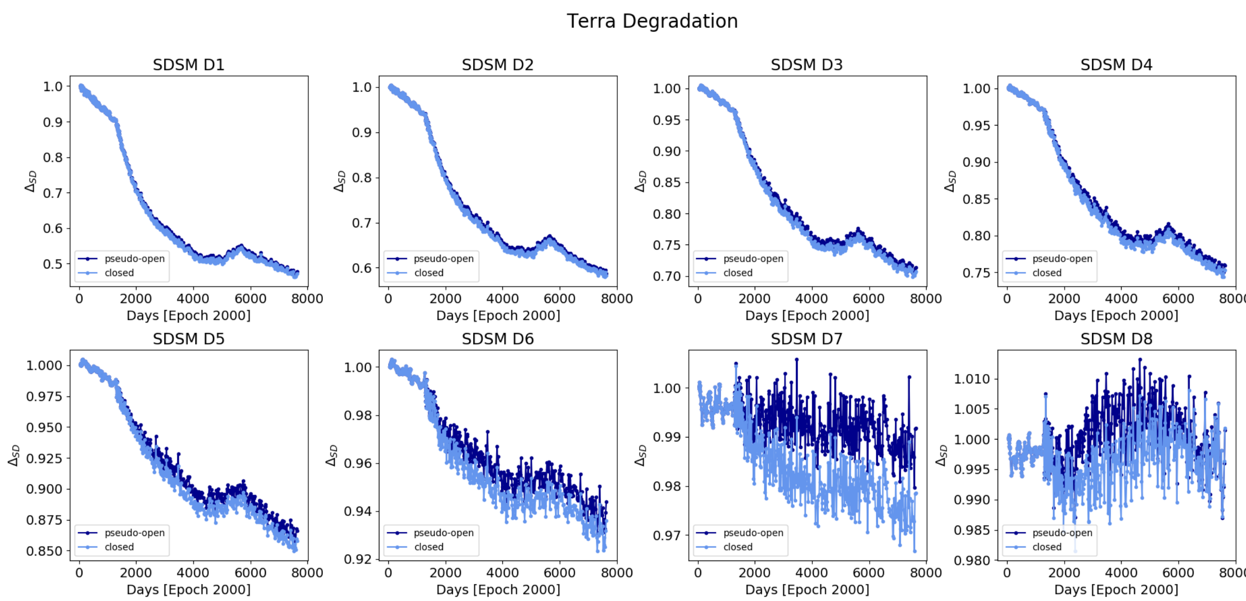

Figure 6. Terra SD degradation at SDSM wavelengths, detectors 1-8. Dark blue points represent psuedo-open Terra degradation data, while light blue points represent measured degradation data in the screen closed configuration. Each data point represents degradation calculated from one SD calibration event. In both cases, the data from mission start through mid-2003 (day 1279) use the screen open configuration.

Once these measured pseudo-open SD degradation values are obtained, we proceed to fit them using a piecewise combination of quadratic exponential and linear exponential fit functions that we nominally use in our SD degradation calculations.[11] A linear interpolation method is then employed to calculate the SD degradation at MODIS RSB wavelengths using the fit SD degradation values at SDSM wavelengths. With these new, fit SD degradation values, we calculate the SD m_1 calibration coefficients and RVS for each RSB band on Terra MODIS.[13]

4. RESULTS

After calculating the SD degradation at SDSM and MODIS wavelengths with the algorithm described above, we implement these new, fit "psuedo-open" SD degradation values in our m_1 coefficient and RVS calculation for

Band	Wavelength [nm]	Day 3000	Day 4795	Day 5755	Day 7685
1	646.5	0.0619%	0.0987%	0.0889%	0.0880%
2	856.7	0.1088%	0.1223%	0.1104%	0.1118%
3	465.6	0.0479%	0.2145%	0.2048%	0.2234%
4	553.7	0.0053%	0.0572%	0.0612%	0.0851%
5	1241.9	0.1892%	0.2099%	0.2204%	0.1042%
6	1629.1	0.0760%	0.0866%	0.0921%	0.0794%
7	2114.3	0.0303%	0.0354%	0.0380%	0.0384%
8	411.8	0.0592%	0.2215%	0.1920%	0.1808%
9	442.1	0.1447%	0.2405%	0.2265%	0.2278%
10	486.9	0.0000%	0.1209%	0.1054%	0.1332%
11	529.7	1.0795%	1.0889%	1.0784%	0.9413%
12	546.8	0.9959%	1.0152%	0.9849%	0.8453%
13	665.6	0.9871%	1.0347%	1.0118%	0.9297%
14	676.7	0.9746%	1.0179%	0.9970%	0.9095%
15	746.4	0.9013%	0.9174%	0.9087%	0.8473%
16	866.2	1.0367%	1.1188%	1.1162%	1.1050%
17	904.1	0.8213%	0.5946%	0.4105%	0.0559%
18	935.3	0.0238%	0.0168%	0.0118%	0.0359%
19	936.1	0.0033%	0.0019%	0.0017%	0.0252%
26	1382.0	0.1330%	0.1491%	0.1572%	0.1456%

Table 1. Summary of m_1 LUT percent differences when RSB calibration is performed using pseudo-open Terra SD degradation compared to official closed SD degradation data. All day numbers are relative to January 1, 2000. For bands 1-4 and 8-10, there is little impact since the long-term m_1 trend correction in both cases is derived from desert sites.

each of the Terra MODIS RSBs. Utilizing the new degradation values in our m_1 coefficient calculation results in a smaller divergence between the lunar and SD m_1 coefficients across all MODIS bands. This change is particularly apparent in Terra MODIS Bands 1, 2, and 13 - 16.

Figure 7 shows closure in the gaps between the lunar and SD m_1 coefficients after the door anomaly when the pseudo-open degradation values are utilized, as well as an overall change in the SD m_1 values on the order of about 0.5% to 1%. Table 1 demonstrates that changes in the m_1 coefficients of this magnitude are present across most bands, with the largest changes seen in Terra bands 11-16 when implementing the pseudo-open SD degradation in our m_1 calculations. These percent differences in Table 1 are calculated using the final m_1 coefficients and represent how the C6.1 m_1 LUT would change if generated using the pseudo-open SD degradation. For Terra bands 1-4 and 8-10, a correction derived using desert data is applied to obtain these final values. We do not observe large changes between the final m_1 coefficients calculated using official SDS closed degradation and the pseudo-open degradation for these bands since the inverse of the gain calculated at the SD AOI is ultimately utilized. Bands that do not implement this correction and utilize OBC data, however, demonstrate changes on the order of 0.5% between the final m_1 coefficients calculated using the two degradation data sets. The difference between the lunar and SD m_1 coefficients calculated using the pseudo-open SD degradation data is decreased over the duration of the mission when comparing to the coefficients calculated using the SDS closed data. Implementing the pseudo-open SD degradation values in our calculations results in SD m_1 coefficient values that align more accurately with our expectations, indicating that the SDS closed data being collected on Terra MODIS may not be accurately representing the degradation of the SD at SDSM and MODIS RSB wavelengths.

In addition to examining the changes exhibited in the calculated m_1 coefficients, we are also interested in examining the effects of implementing these pseudo-open degradation data in our RVS calculations. As mentioned in Section 3, we observe a sharp change in the RVS for bands that use OBC data in their calculations that is synced with the SDD anomaly. Since RVS depends strictly on the reflectance of MODIS's scan mirror, we would not anticipate changes that are synced with the SD degradation. By utilizing the pseudo-open SD degradation

data instead of the SD degradation data collected in the screen closed configuration, we would anticipate bands with OBC based RVS to exhibit less of a severe change in their RVS trends after the SDD anomaly. Figure 8 confirms this idea for Band 13, which strictly uses OBC data in its RVS calculations. We see an overall RVS change of approximately 1% for AOI near the edge of scan, versus a change on the order of 2% when the SDS closed data were implemented. The pseudo-open RVS changes demonstrated by Band 13 for the duration of the Terra mission are much more congruous with the changes we see in Band 1 in Figure 3, though they are still not in perfect agreement.

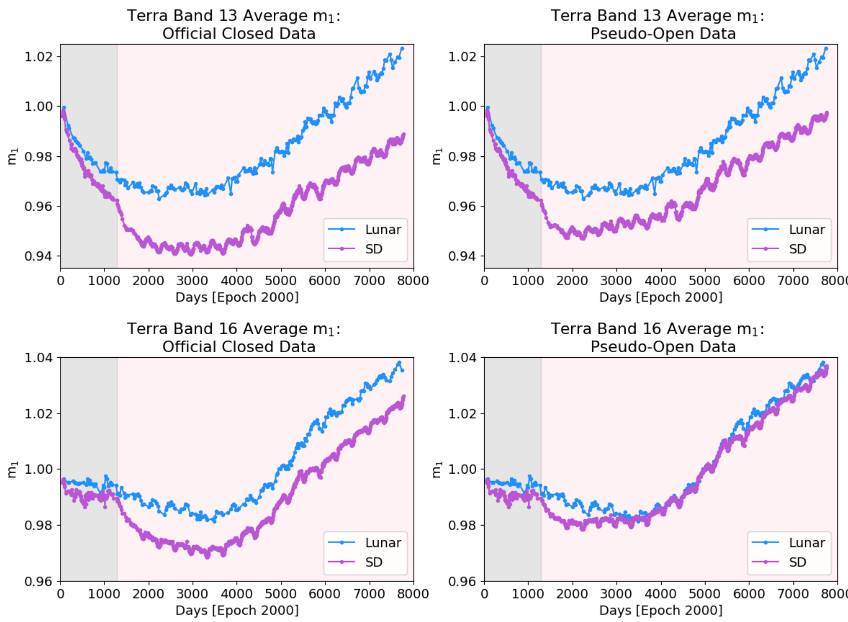

Figure 7. Terra Band 13 and Band 16 average m_1 coefficients. Left panels show lunar data (blue) and SD data (magenta) using official Δ_{SD} calculated using Terra SDS closed data. Right panels shows lunar data (blue) and SD data (magenta) using "pseudo-open" Δ_{SD} data calculated using the methods described in Section 3. Gray region highlights dates before Terra SDD anomaly, while pink region highlights dates after anomaly.

5. DISCUSSION

The changes we see in the SD m_1 coefficients and RVS trends when we implement the pseudo-open degradation data indicate that the Terra SDS closed data may not sufficiently be characterizing on-board changes occurring in the SD's reflectance and consequently MODIS's optics. The result is potential inaccuracies in the C6/C6.1 m_1 and RVS calibration of Terra bands 11-19 on the order of 1% or perhaps more, depending on band. Shorter wavelength Terra bands derive long-term calibration trends from desert data and should not be significantly impacted by this SD degradation inaccuracy.

We see a clear difference between the open and closed data for Aqua as indicated in Figures 4 and 5, and this work has shown that a similar discrepancy likely exists across the mission for Terra MODIS. The reason for this discrepancy is still unknown. It is possible that the SDSM detectors may be exhibiting nonlinear gain, but further investigation would be required. It is also possible that the differences are due to a temperature dependence of the SDSM detectors that is not corrected in our algorithm, or due to differences in stray light in the SDSM system in the two configurations. It is possible that Terra MODIS will be able to acquire some calibrations with the SDS in the open configuration as a part of end of mission calibration and testing in the next few years, which would provide validation of how the SDS open and closed calibration results have changed for Terra MODIS.

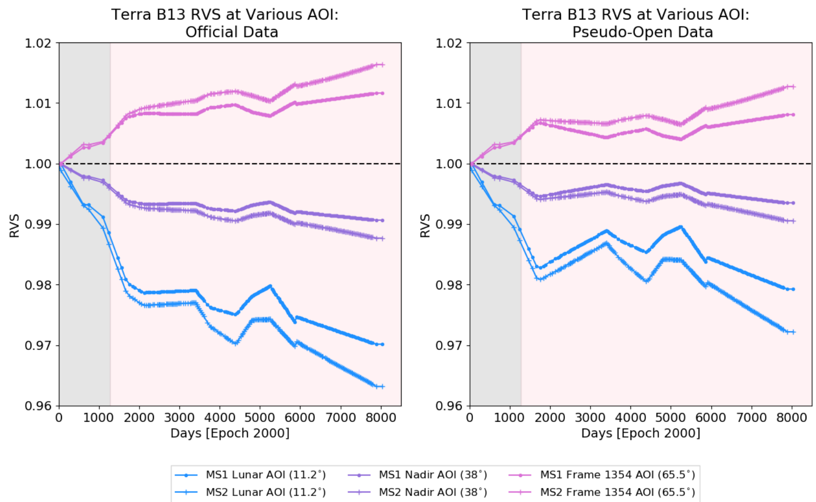

Figure 8. Terra Band 13 RVS at various AOI. Left panel represents official data calculated using closed SD calibration data, while right panel utilized pseudo-open SD data in RVS calculation. Gray region highlights dates prior to SDD anomaly, while pink region highlights dates after this event.

The results presented here improve our understanding of the SDSM system and errors that arise in the calculation of the SD degradation. This could help improve the calibration of Terra MODIS RSB in the future. It may also be useful in the SDSM and SD characterization for other remote sensing instruments that use an SD for RSB calibration, particularly the VIIRS instruments on the SNPP and NOAA-20 satellites[14–16] which have a very similar SD/SDSM design as MODIS.

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